# Enabling Daily Tracking of Individual's Cognitive State with Eyewear

Soha Rostaminia
College of Information and Computer Sciences
University of Massachusetts Amherst
Advisor: Prof. Deepak Ganesan
srostaminia@cs.umass.edu

## Abstract

The ability to continuously monitor one's cognitive state of the mind has implications for a variety of application domains. The goal of this work is the design of novel eyewear solutions in order to track various cognitive states, with the focus of being low-power, unobtrusive, and robust to confounders present in everyday scenarios. We propose the following contributions: i) design and implementation of a system, iLid, that is able to extract key features of fatigue and drowsiness, ii) design of a privacy-sensitive system, W!NCE, for detecting various facial expressions and pain instances, and iii) design of an all-textile sleep monitoring system that can continuously measure various physiological signals such as brain activity, eye movement patterns, heart rate, and breathing rate without impacting sleep.

## 1 Introduction

Research studies show that sleep deprivation causes severe fatigue, impairs attention and decision making, and affects our emotional interpretation of events, which makes it a big threat to public safety, and mental and physical well-being. Hence, it would be most desired if we could continuously measure one's drowsiness and fatigue level, their emotion while making decisions, and assess their sleep quality in order to provide personalized feedback or actionable behavioral suggestions to modulate sleep pattern and alertness levels with the aim of enhancing performance, well-being, and quality of life.

While there has been decades of studies on wearable devices, we still lack good instruments to measure individual's cognitive state in natural settings. For designing such a system, there are three key factors that need to be addressed;

**Unobtrusiveness:** The human brain and eye reveal a great deal about our current cognitive state, which makes head the most appealing place to extract information from. Since head is the most visible part of the human body, it is extremely important that such a wearable system can be worn for long periods without physical discomfort and that it does not inflict mental burden on the user.

**Energy-efficiency:** From an energy-efficiency perspective, the key challenge is ensuring that all the desired measures can be extracted at extremely low power. This can allow us to design small form-factor devices that can be easily integrated into a variety of eyewear platforms, and also enables long hours operation with small battery units.

**Robustness:** In order to have good measures of the cognitive state, and hence trigger timely personalized interventions, the system should be robust enough to provide accurate measures continuously in various real-life situations.

To summarize, the goal of this work is the design and implementation of eyewear solutions with the focus of addressing the design factors specified above (shown in Figure 1), in order to track three important cognitive states: 1) fatigue and drowsiness, 2) emotion and pain state, and 3) sleep quality.

## 2 Methodology

In order to infer individual's cognitive state of the mind such as, fatigue, emotion, and sleep, we need to gather information in the form of various physiological signals. Harvesting these signals requires a lot of energy and good-quality sensors to ensure high signal-to-noise-ratio (SNR). In this section, we explain our proposed solutions to design a fully robust, low-power, and comfortable wearable for each of the three problems.

### 2.1 Fatigue and Drowsiness Tracking

As the first contribution of this work, we present a system, iLid [4], that is able to extract key features of fatigue at low power and high frame rate from a wearable eye tracker in natural settings.

Many decades of experimental studies have identified that eye features such as percentage of eye closures, blink duration, and blink frequency are the most significant features of interest for predicting the level of fatigue. Despite our understanding of how to measure fatigue, we lack good instruments to measure these eye parameters robustly in natural settings. Most wearable eye trackers that provide high-resolution data are bulky and power-hungry and are not suitable for continuous daily wear. In iLid, we develop methods that dramatically reduce the cost of sensing and processing by sampling a small subset of pixels on an imager (a few

International Conference on Embedded Wireless Systems and Networks (EWSN) 2021
17–19 February, Delft, The Netherlands 
ISBN: 978-0-9949886-5-2

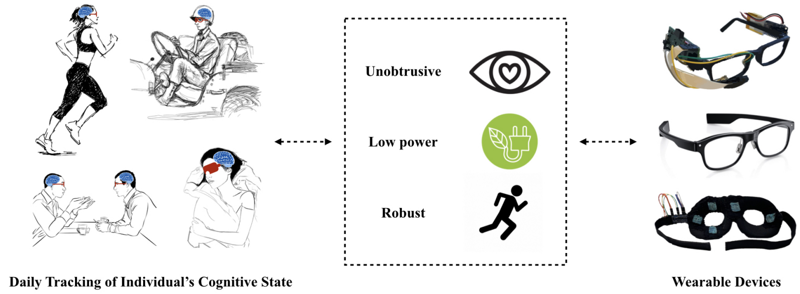


**Figure 1. My research focus is to enable daily tracking of individual's cognitive state by design and implementation of low power and robust algorithms for computational eyewears.**

columns of pixels) and processing these pixels in real time to extract the salient features for fatigue detection. We develop light weight classification-based methods to extract blink and eyelid features.

Our results show that iLid can detect blinks with a high F1 score (about 0.90) and measure blink duration with errors as low as 2.4% in both indoor and outdoor conditions. We show that our system has an end-to-end power consumption of 46mw at 100Hz. We also provide an exhaustive characterization of robustness of the technique under many settings and we compare iLid against a state-of-the-art wearable electrooculography (EOG) eyeglass, J!NS MEME [1], and show the strengths of vision-based over EOG-based fatigue measures.

## 2.2 Facial Expressions Tracking

The second contribution of this work is design and implementation of a system, W!NCE [3], that is able to detect upper facial expressions by leveraging only three small dry electrodes on the nose-bridge of a normal looking pair of glasses (J!NS MEME) in an unobtrusive manner in natural settings.

While facial expressions can easily be monitored with cameras pointing at the face, this is impractical in ambulatory settings and raises privacy issues in personal spaces. An intriguing new alternative that has emerged is wearable EOG. In W!NCE, we re-think what is considered signal and what is noise for EOG-based sensing — unlike traditional uses of EOG where the signal is eye movement and noise is all other activity, the information we need is contained in the noise. We also design a motion artifact removal pipeline that leverages accelerometer and gyroscope information to remove the artifacts caused by head motion and large body movement. We evaluate W!NCE in both stationary and ambulatory settings, and show via a systematic and in-depth exploration of signal characteristics that wearable EOG can be very effective in detecting upper facial actions (F1 score of 0.84). We demonstrate the utility of W!NCE for continuous pain monitoring and show that W!NCE accurately detects the instances when pain is induced as well as the action units involved in the individual's reaction to pain.

## 2.3 Sleep Tracking

During the past decades, there has been a vast body of work on both wearable (e.g. Fitbit and Oura Ring) and non-wearable (e.g. bedside monitors) sleep monitoring approaches. The problem with existing devices is that they are not yet capable of accurately detecting different stages of sleep, such as Rapid Eye Movement (REM) and non-REM sleep, since they usually solely estimate the sleep stages based on the heart rate, breathing, and body movement signals. In order to be able to accurately detect the onset of the sleep stages, we need to have information about brain activity and eye-movement patterns. Therefore, there is a need for a device that can sense all these physiological signals in an unobtrusive, continuous, and low-power manner.

As the third major contribution of this thesis, we propose the design of a lightweight and all-textile sleep mask, PhyMask, that can be worn continuously during long duration of wear without impacting sleep and simultaneously measure eye parameters (EOG), brain activity (EEG), and heart and respiratory rate. We show that our system can also detect head posture on the pillow and body movements without requiring any accelerometer and gyroscope sensors. In collaboration with Chemistry Department at UMass Amherst, we have designed a first-of-its-kind, thread-based, reusable wet electrode to measure EOG and EEG signals [2], and a pressure-sensitive, ionic fabric electrode to capture pulse wave-forms and respiration rate from head. Our platform includes a Bluetooth low energy (BLE) transmitter for wireless data transfer, enabling portable use in any number of environments. This is an ongoing study and we plan to collect longitudinal sleep data from both healthy individuals and sleep disorder patients, and compare the PyhMask's performance in accurate sleep stage estimation with Polysomnography and current commercially-available sleep monitoring devices such as Fitbit and Oura Ring.

# 3 References

[1] Jins meme eyewear, Oct. 2015. https://jins-meme.com/en/.

[2] S. Z. Homayounfar, S. Rostaminia, A. Kiaghadi, X. Chen, E. T. Alexander, D. Ganesan, and T. L. Andrew. Multimodal smart eyewear for longitudinal eye movement tracking. *Matter*, July 2020.

[3] S. Rostaminia, A. Lamson, S. Maji, T. Rahman, and D. Ganesan. W!nce: Unobtrusive sensing of upper facial action units with eog-based eyewear. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, 3(1), Mar. 2019.

[4] S. Rostaminia, A. Mayberry, D. Ganesan, B. Marlin, and J. Gummeson. ilid: Low-power sensing of fatigue and drowsiness measures on a computational eyeglass. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, 1(2):23:1–23:26, June 2017.